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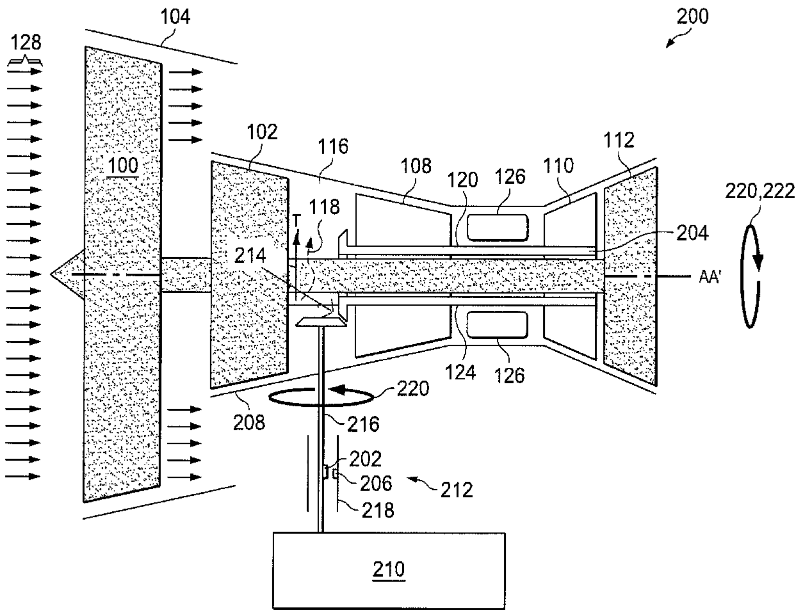

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(57) Abrégé/Abstract:
A method of integrating an electric motor or generator as part of an aircraft engine shaft. The motor is used to rotate the rotor so as to cool the rotor in a temperature gradient. The generator is used to provide power to the aircraft.

ABSTRACT

A method of integrating an electric motor or generator as part of an aircraft engine shaft. The motor is used to rotate the rotor so as to cool the rotor in a temperature gradient. The generator is used to provide power to the aircraft.

ENGINE SHAFT INTEGRATED MOTOR

BACKGROUND

1. Field

The present disclosure relates to a system for connecting a motor and/or generator to an aircraft gas turbine engine.

2. Description of the Related Art

FIG. **1** illustrates an aircraft engine comprising a fan **100**, a low pressure (LP) compressor **102**, a fan case **104**, an engine casing **106**, a High Pressure (HP) compressor **108**, a HP turbine **110**, a LP turbine **112**, and a LP shaft **114** connecting the LP compressor **102** and the LP turbine **112**. After engine shutdown on the ground, residual hot air **116** in the engine core rises **118** and is trapped by the engine casing **106**. As the hot air rises **118**, the upper portion **120** of the HP compressor's (engine's rotor) **108** rotor shaft **122** becomes hotter than the lower portion **124** of the rotor shaft **122** and causes uneven cooling and thermal deformation of the engine rotor shaft **122** (i.e., rotor bowing, where the upper portion **120** of the rotor shaft **122** becomes longer than the lower portion **124**). Upon engine restart (e.g., prior to fuel ignition in the combustor **126**), even tiny fractions of rotor shaft bowing can cause the HP compressor (engine's rotor) **108** to rub against the engine's casing **106**. The rub causes vibrations (manifested as disconcerting noise in the aircraft cabin) or even damage to the aircraft (e.g., engine damage, damage to the engine case lining, damage to the air pre-cooler used by the environmental control system, or damage to other accessories).

One method to mitigate these problems is to build the engine with wider cold build clearances ("opened up" clearances), so that the compressor rotor shaft **122** can bow without causing blades to rub on the engine casing **106**. However, more advanced engine designs prefer less "gap" between the engine casing and the compressor rotors (tighter "cold build clearances") to reduce air leakage and improve thrust specific fuel

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consumption (TSFC). Thus, the overriding need to reduce fuel consumption renders wider cold build clearances less desirable. Indeed, as ever tighter cold build clearances are implemented, the problems caused by engine rub will become more severe.

Conceivably, an engine architecture could add rotor stiffening or bearing arrangements to reduce the amount of rotor shaft bow that is physically possible. However, these architecture changes would add weight and manufacturing cost to the engine.

Other methods of mitigating rotor shaft bow comprise rotating the shaft (**1**) so that the shaft cools uniformly, returns to thermal equilibrium, and straightens, and/or (**2**) so that centrifugal forces straighten the bow. The shaft rotation is achieved (**1**) by motoring the engine at relatively low revolutions per minute (RPM) after starting the engine (but before running the engine at high RPM) and/or (**2**) using an Engine Turning Motor (ETM) to turn the rotor shaft when the engine is off.

However, conventional methods for providing power to the ETM or the engine so as to straighten the bow can be problematic. Some smaller aircraft, such as the Boeing **737** airplane, fly into remote airports where facility power is not available to power the ETM or engine. Furthermore, auxiliary power unit (APU) power on the aircraft is not always available to power the engine or ETM because some airports limit APU use at gates due to emissions and noise concerns and aircraft are not powered when they are towed between gates. In addition, airplanes may operate with a nonfunctional APU or the powering of the ETM or engine may cause undesirable APU wear (extended motoring prolongs the APU's exposure to main engine start (MES) mode, reducing APU life). Finally, the use of lithium-ion and nickel-cadmium batteries for powering the ETM is problematic due to high failure rates and flammability concerns associated with the engine environment (extreme heat, extreme cold, and high vibration).

Moreover, rotating the shaft shortly before departure causes departure delays, especially if reduced engine clearances require turning the rotor at low speeds. These delays not only inconvenience the passengers but also increase costs associated with increased waiting times and parking fees.

What is needed then, is a more efficient method for mitigating rotor shaft bowing that simplifies ground logistics.

SUMMARY

The present disclosure describes a motor (e.g., a direct current motor), including a gas turbine engine including a rotor shaft and a first casing around the rotor shaft; a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft; one or more permanent magnets attached to the rotor shaft and/or the drive shaft; one or more electromagnets attached to the first casing and/or the second casing; and a power supply connected to the electromagnets. The rotor shaft turns when (**1**) the electromagnets generate first magnetic fields in response to current supplied from the power supply and (**2**) the first magnetic fields interact with second magnetic fields generated by the permanent magnets.

In one embodiment, a nacelle houses the gas turbine engine. When the nacelle traps hot air, a temperature gradient is created perpendicular to the longitudinal axis of the rotor shaft. However, when the motor is operated, interaction of the first and second magnetic fields turns the rotor shaft so as to reduce or prevent thermal bowing of the rotor shaft in the temperature gradient when the gas turbine engine is cooling down after shutdown of the gas turbine engine.

The present disclosure further describes a power generation device, including a gas turbine engine including a rotor shaft and a first casing around the rotor shaft; a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft; one or more permanent magnets attached to the rotor shaft and/or the drive shaft; one or more coils attached to the first casing and/or the second casing; and an energy storage device (e.g., a battery) connected to the coils. The energy storage device stores electrical energy generated by the coils when (**1**) the engine is running so as to rotate the permanent magnets on the shaft and (**2**) magnetic fields generated by the permanent magnets

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interact with the coils. The electrical energy is used to reduce transient and peak electrical power demands on the engine.

The present disclosure further describes a power generation device, comprising a gas turbine engine including a rotor shaft and a first casing around the rotor shaft; a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft; one or more permanent magnets attached to the rotor shaft and/or the drive shaft; one or more coils attached to the first casing and/or the second casing; and an aircraft electrical system connected to the coils. The aircraft electrical system receives electrical power generated by the coils when (**1**) the engine is running so as to rotate the permanent magnets on the shaft and (**2**) magnetic fields generated by the permanent magnets interact with the coils. The electrical power is used to either power an airplane system or an engine system.

In one embodiment, an aircraft comprises a computer connected to the engine. The current generated in the coils powers the electrical system during times of peak electrical loading of the electrical system. In this case, fuel consumption in the gas turbine engine can be reduced (as compared to when the gas turbine engine is used to power the electrical system without the current from the power generation device).

In one embodiment, there is provided a motor. The motor includes a gas turbine engine including a rotor shaft and a first casing around the rotor shaft. The method further includes a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft. The motor further includes one or more permanent magnets. The one or more permanent magnets are attached to the rotor shaft, or the one or more permanent magnets are attached to the drive shaft, or one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft. The motor further includes one or more electromagnets. The one or more electromagnets are attached to the first casing, or the one or more electromagnets are attached to the second casing, or one or more of the electromagnets are attached to the first casing and one or more of the electromagnets are attached to the second casing. The motor further includes a power supply connected to the electromagnets.

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The rotor shaft turns when the electromagnets generate first magnetic fields in response to current supplied from the power supply, and the first magnetic fields interact with second magnetic fields generated by the permanent magnets.

The motor may include a nacelle housing the gas turbine engine. The rotor shaft may have a longitudinal axis. The nacelle may trap air, creating a temperature gradient perpendicular to the longitudinal axis, and interaction of the first and second magnetic fields turns the rotor shaft so as to reduce or prevent thermal bowing of the rotor shaft in the temperature gradient when the gas turbine engine is cooling down after shutdown of the gas turbine engine.

The permanent magnets may be on the rotor shaft and the electromagnets may be on the first casing.

The motor may include a direct current (DC) motor integrated with the gas turbine engine. The DC motor may include the permanent magnets and the electromagnets.

The permanent magnets may be on the drive shaft and the electromagnets may be on the second casing.

The gas turbine engine may include a high pressure compressor including the rotor shaft.

The gearbox may not include an engine turning motor.

In another embodiment, there is provided a power generation device. The power generation device includes a gas turbine engine including a rotor shaft and a first casing around the rotor shaft. The power generation device further includes a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft. The power generation device further includes one or more permanent magnets. The one or more permanent magnets are attached to the rotor shaft, or the one or more permanent magnets are attached to the drive shaft, or one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft. The power generation device further includes one or more coils. The one or more coils are attached to the first casing, or the one or more coils are attached to the second casing, or one or more of the coils are attached to the first casing and one or more of the coils are attached to the second casing. The power generation device further includes an energy storage device connected to the coils. The energy storage device stores electrical energy generated by the coils when the engine is running so as to rotate the permanent magnets on the shaft, and magnetic fields generated by the permanent magnets interact with the coils; and the electrical energy reduces transient and peak electrical power demands on the engine.

The energy storage device may include a battery.

The permanent magnets may be on the rotor shaft and the one or more coils may be on the first casing.

The permanent magnets may be on the drive shaft and the one or more coils may be on the second casing.

The gas turbine engine may include a high pressure compressor including the rotor shaft.

In another embodiment, there is provided a power generation device. The power generation device includes a gas turbine engine including a rotor shaft and a first casing around the rotor shaft. The power generation device further includes a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft, and one or more permanent magnets. The one or more permanent magnets are attached to the rotor shaft, or the one or more permanent magnets are attached to the drive shaft, or one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft. The power generation device includes one or more coils. The one or more coils are attached to the first casing, or the one or more coils are attached to the second casing, or one or more of the coils are attached to the first casing and one or more of the coils are attached to the second casing. The power generation device includes an aircraft electrical system connected to the coils. The aircraft electrical system receives electrical power generated by the coils when the engine is running so as to rotate the permanent magnets on the shaft, and magnetic fields generated by the permanent magnets interact with the coils.

The electrical power may be used to either power an airplane system or an engine system.

The gearbox may not include an engine turning motor.

The permanent magnets may be on the rotor shaft and the one or more coils may be on the first casing.

The permanent magnets may be on the drive shaft and the one or more coils may be on the second casing.

An aircraft may include the motor or power generation devices above and a computer connected to the engine. The current may power the electrical system during times of peak electrical loading of the electrical system, and the computer may reduce fuel consumption in the gas turbine engine as compared to when the gas turbine engine is used to power the electrical system during the times of peak electrical loading without the current from the coils.

The power generation device may include a brushless DC generator integrated with the engine, wherein the brushless DC generator comprises the permanent magnets and the coils.

The gas turbine engine may include a high pressure compressor including the rotor shaft.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** is a cross-sectional schematic diagram of a gas turbine engine.

FIG. **2**A is a cross-sectional schematic of a gas turbine engine according to one or more embodiments, showing the rotor shaft and the gearbox mounted to the fan case.

FIG. **2**B is a close up view of the engine in FIG. **2**A, illustrating an embodiment of a motor or generator and positioning of the magnets and coils in the motor.

FIG. **2**C illustrates an embodiment wherein the magnets and coils are positioned in a transmission connected to the rotor shaft.

FIG. **3**A illustrates a cross-section of the shaft in a plane perpendicular to the longitudinal axis AA' (i.e., as viewed along the longitudinal axis AA'), showing an embodiment of a motor, including positioning of the magnets and the electromagnets in the motor and connection of the driving circuit so as to energize the electromagnets.

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FIG. **3**B is a diagram illustrating an exemplary timing sequence for applying voltage pulses that energize the electromagnets in the motor.

FIG. **3**C is a diagram illustrating another exemplary timing sequence for applying voltage pulses that energize the coils in the motor.

FIG. **4**A illustrates a cross-section of the shaft in a plane perpendicular to the longitudinal axis AA' (i.e., as viewed along the longitudinal axis AA'), illustrating an embodiment of a generator, including positioning of the magnets and the coils in the generator and connection of a circuit to the generator.

FIG. **4**B is a diagram of an aircraft embodiment illustrating the coils connected to an energy storage device and electrical system.

FIG. **5** is a flowchart illustrating an exemplary method of fabricating an integrated motor or generator.

FIG. **6** illustrates an exemplary computer system used to implement processing elements.

DESCRIPTION

In the following description, reference is made to the accompanying drawings which form a part hereof, and which is shown, by way of illustration, several embodiments. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present disclosure.

Technical Description

Motors and generators, such as brushless direct current (DC) motors and generators, are fabricated by attaching permanent magnets on a rotor and using a series of electromagnets or coils on a fixed structure (stator) surrounding the rotor.

The present disclosure describes integrating the motor and/or generator in an airplane engine, wherein the airplane engine's shaft comprises the rotor and an engine casing or fixed mounting in the engine comprises the stator.

FIG. **2**A and FIG. **2**B illustrate a gas turbine engine **200** including permanent magnets **202** attached to the rotor shaft **204**; and a series of coils **206** (or

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electromagnets comprising coils **206**) attached on a casing **208** surrounding or around the shaft **204**. FIG. **2**A further illustrates a gearbox **210** attached to the casing **104**.

FIG. **2**C illustrates a gas turbine engine **200** including a rotor shaft **204** and a first casing **208** around the rotor shaft **204**; a transmission **212** connecting the rotor shaft **204** to a gearbox **210**, the transmission **212** comprising a bevel gears **214** and a drive shaft **216**; a second casing **218** around the drive shaft **216**; one or more permanent magnets **202** attached to the drive shaft **216**; and one or more coils **206** (or electromagnets comprising coils **206**) attached to the second casing **218**.

In a motor embodiment, the permanent magnets **202** are repelled and/or attracted by the series of electromagnets, thereby causing the shaft **204**, **216** to rotate **220**. In one embodiment, the gearbox **210** does not include an engine turning motor because the motor **300** comprising permanent magnets **202** and electromagnets **302** is used to turn the rotor shaft **204**.

In a generator embodiment, the rotor shaft **204** and the permanent magnets **202** rotate **220** (e.g., when the engine is operated in combustion mode with an air **128** intake) and the permanent magnets **202** induce current in the coils **206** when magnetic fields generated by the magnets **202** move through or interact with the coils **206**.

First Example: Integrated Motor Operation

FIG. **3**A illustrates an integrated motor **300** comprising a plurality of electromagnets **302** comprising coils **206** (numbered **1**-**6**) attached to the inner surface **304** of the casing **208**. The electromagnets **302** and the permanent magnets **202** are positioned so that the shaft **204** rotates **306** about axis AA' when first magnetic fields M**1** generated by the electromagnets **302** interact with (or have a force interaction with) second magnetic fields M**2** generated by the permanent magnets **202**.

In one or more embodiments, the permanent magnets **202** and the coils **206** are disposed symmetrically about a center point P on the longitudinal axis AA'.

Electrical wires **308** connect a driving circuit **310** (comprising or connected to a power supply **310**a) to the electromagnets **302**. The power supply **310**a and circuit **310** supply current to the electromagnets **302** so as to generate the first magnetic fields M**1**. The current comprises a pulse sequence or waveform so that the first magnetic fields M**1** are switched on and off to repel and/or attract A the permanent magnets **202** with synchronized timing that causes the rotor shaft **204** to turn **306**.

FIG. **3**B illustrates a timing sequence for energizing the coils **206**, wherein coil **1** is first energized using a voltage so that coil **1** has a magnetic field M**1** with South (S) polarity that attracts the magnet **202** having North (N) polarity. At later times, coils **2** and **3** *are energized so as to attract the magnet having* N *polarity as the magnet nears* coils **2** and **3**, respectively. In this example, diametrically opposite coils are electrically connected (coil **1** is connected to coil **4**, coil **2** is connected to coil **5**, and coil **3** is connected to coil **6**) so that the magnetic fields in the opposite coils have opposite polarity (i.e., coil **1** has N polarity when coil **4** has S polarity).

FIG. **3**C illustrates another timing sequence for energizing the coils **206**, wherein coils **1** and **5** are connected and first simultaneously energized using voltages so that coil **1** has a magnetic field with S polarity that attracts the magnet **202** having N polarity and coil **5** has a magnetic field with polarity N to repel the magnet **202** having N polarity. Coils **2** and **6** are also simultaneously energized but out of phase with coils **1** and **5**, so as to attract and repel the magnet having N polarity, respectively. Coils **3** and **1** are then subsequently energized at the same time so as to attract and repel the magnet having N polarity.

Second Example: Integrated Generator Operation

FIG. **4**A illustrates an integrated generator **400** comprising the coils **206** and the permanent magnets **202** positioned so that a current is generated in the coils **206** when the shaft **204** is rotating **402** (as a result of the engine **200** running in combustion mode and burning fuel when air **128** is inputted into the engine). The moving magnetic fields M**2** generated by the permanent magnets **202** interact with, or pass through, the coils **206** and generate current according to Faraday's law.

Electrical wires **308** connect the coils **206** to a circuit **404** that comprises, or is connected to, an energy storage device **406** (e.g., battery) and/or an electrical system **408** on the aircraft, so that the current generated in the coils **206** charges the energy storage device **406** and/or supplies power to the electrical system **408**.

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The aircraft's electrical system **408** (e.g., powering air conditioning, cabin pressurization, and plumbing) adds various electrical loads during operation of the aircraft. Typically, some of the engine's rotational energy is converted into electrical energy in order to handle these additional loads. In this case, the engine then has to burn more fuel to maintain its original rotation speed. Consequently, the engine must be operated in such a way (i.e., with high enough speed) that it can withstand a sudden electrical load and maintain stability.

In one embodiment, the airplane extracts electrical power from the coils **206** in the integrated generator **400** to help power the electrical systems on the aircraft at various times, e.g., during peak electrical demands. This alleviates the burden on the engine, enabling less fuel burn and lower engine speeds for most of the flight while still accommodating sudden electrical loads applied to the electrical system.

FIG. **4**B illustrates an airplane **410** comprising a computer **412**, **600** comprising an engine control system connected to the engine **200** housed in a nacelle **414**; and the electrical system **408** and energy storage device **406** connected to the coils **206** via wiring **416**. The current from the coils **206** is used to power the electrical system, e.g., during times of peak electrical loading of the electrical system. The computer **412** or **418** reduces fuel consumption in the gas turbine engine **200** as compared to when the gas turbine engine is used to power the electrical system without the integrated generator **400**. In another example, the integrated generator **400** is used as a load source or sink by the engine's control system so as to aid engine operability and engine acceleration rates, e.g., during abnormal flight conditions.

Peak electrical demands also impact engine sizing conditions. Conventionally, larger engines are used to mitigate for worst case energy scenarios. Use of the integrated generator system **400** to power the electrical system **408** enables implementation of smaller, lighter engines that burn less fuel.

Third Example: Rotor shaft bow mitigation

Air **128** inputted into the nacelle **414** or fan casing **104** is trapped in the nacelle **414** and is heated by the engine **200** so as to form trapped hot air **116**. The trapped hot air **116** creates a temperature gradient T perpendicular to a longitudinal axis AA' of

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the rotor shaft **204** . In one embodiment, current I is provided to the electromagnets **302** so as to drive the shaft **204** when the gas turbine engine **200** is cooling down (e.g., after engine shut down) in the temperature gradient T, thereby reducing or preventing thermal bowing of the rotor shaft **204** in the temperature gradient T.

In one or more embodiments, the integrated motor **300** rotates **306** the rotor shaft **204** at one or more speeds, using one or more torques, and/or for one or more durations, so as to reduce or prevent the thermal bowing of the rotor shaft **204** in the temperature differential. Examples of rotation speeds include, but are not limited to, low speeds such as between **0.5-2.0** rpm (revolutions per minute).

Rotation **306** of the rotor shaft **204** includes, but is not limited to, pulsed rotation, continuous rotation, a combination of both pulsed rotation and continuous rotation, clocked rotation, and/or sporadic rotation.

In one embodiment, the integrated motor **300** turns the rotor shaft **204** slowly so that the rotor shaft **204** is slowly cooled and returned to thermal equilibrium. In another embodiment, the power to the motor **300** from the circuit **310** is pulsed or supplied periodically (i.e. once every **10** minutes, **30** minutes, hour, etc.) over a period of time (e.g., **8** hours) so that the rotor shaft **204** is rotated **220** periodically to promote an even temperature profile in the rotor shaft **204**.

In another periodic pulsing scheme, power supplied to the motor **300** from the circuit **310** is applied every plurality of minutes (e.g. every **5-15** minutes) so that the rotor moves a partial turn or in increments. In one embodiment, partial turns are 'clocked,' e.g., for a one-half turn. In another example, a current pulse from the circuit **310** provides random rotor shaft **204** movement. In one embodiment, pulse modulation is achieved by programming the motor **300** to transfer increments of torque. In one embodiment, the motor **300** rotates **220** the shaft **204** by turning the shaft **204** in one or more increments comprising a partial revolution of the shaft.

In one example, the rotation speed and duration are such that the probability of a compressor rub is less than e-**8** per flight-hour.

Example System Features

One or more embodiments of the integrated motor/generator **300**, **400** are installed in an aircraft using components such that:

- the aircraft is capable of being dispatched for at least **10** days after a failure of the integrated motor/generator;
- failure of the integrated motor/generator does not require line maintenance to dispatch the aircraft;
- failure of the integrated motor/generator does not interfere with engine operation, and in particular, does not interfere with engine start;
- failure rate of the integrated motor/generator system is e-**5** per flight hour or better;
- the integrated motor/generator is sufficiently reliable that a backup scheme is not required (e.g., the integrated motor/generator has a reliability of at least e-**6** per flight hour or at least e-**7** per flight hour);
- the integrated motor/generator has a lock out feature, in case unforeseen issues arise and the system must be easily disabled;
- energy demands for rotating the rotor and reducing the thermal bowing are reduced as compared to systems using an electric motor to rotate the rotor; and/or
- the installation and certification is easier as compared to systems using an electric motor to rotate the rotor (e.g., the integrated motor/generator does not include a new ignition source or fuel source adding to engine fire protection designs).

Process Steps

FIG. **5** illustrates a method of fabricating a motor or generator, according to one or more embodiments. The method comprises one or more of the following steps.

Block **500** represents attaching, one or more magnets to an outer surface **204**a of a shaft **204**, **216**, e.g., as illustrated in FIG. **2**B, FIG. **2**C, FIG. **3**A, and FIG. **4**.

Examples of methods for attaching the magnets **202** include, but not limited to, printing the magnets on the shaft **204**, **216** (using, for example, ink jet printing, functional ink, or magnetic ink), painting the magnets **202** on the shaft **204**, **216**, mechanically attaching the magnets **202** to the shaft **204**, **216** (using, for example, adhesive or fasteners), or welding the magnets **202** onto the shaft (reference used as bevel gear), **216** (using, for example, dry welding). Examples of magnets **202** include, but are not limited to, permanent magnets such as rare-earth magnets (e.g., Neodymium magnets).

In one or more embodiments, the magnets **202** are disposed concentrically about a point P on the longitudinal axis AA'. In one example, the magnets **202** are disposed in pairs on the shaft **204**, **216**, wherein the magnets **202** in each pair are placed on opposite sides of the shaft **204**, **216** or diametrically opposite one another. In one embodiment, the magnets **202** are placed symmetrically about the shaft **204**, **216**. In yet another embodiment, the magnets **202** are disposed in a ring around a center point P of the shaft **204**, **216**. In one or more embodiments, the magnets **202** comprise materials selected after a materials analysis determining the materials' ability to withstand the high temperature environment in the engine **200**.

Block **502** represents attaching coils **206**, or electromagnets **302** each comprising at least one coil **206**, to an inner surface **304** of a casing **208** or sheath.

In one or more embodiments, the coils **206** comprise metal wires coated with an insulator. Examples of metal used for the wires include, but are not limited to, aluminum or copper. Examples of the insulator include, but are not limited to, high temperature polymers or ceramics. In one or more embodiments, the coil **206** comprises twisted shielded pairs of wires.

In one or more embodiments, the coils **206** are disposed in pairs on the casing **208**, **218** , wherein the coils **206** in each pair are placed on opposite sides of the casing **208**, **218** or diametrically opposite one another. In another embodiment, the coils **206** are placed symmetrically about the shaft **204**, **216**. In yet another embodiment, the coils **206** are disposed in a ring around a center point P of the shaft **204**, **216** or are wrapped around the rotor shaft **204**, **216**. In one or more embodiments, the coils **206** are fabricated from materials selected after a materials

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and/or metallurgy analysis determining the materials' ability to withstand the high temperature environment in the engine **200**.

The coils **206** are attached using a variety of methods including, but not limited to, using adhesive.

In one or more embodiments, the magnets **202** are attached to the shaft **204**, **216** in a relatively cold area of the shaft **204**, **216**, so as to reduce risk of damage to the coils and the magnets.

Block **504** represents optionally positioning sensors, e.g., on the casing **208**, **218** so as to measure a location of the magnets **202** and/or coils **206** as they rotate **306**. The location information is used to optimize timing of the current/voltage waveforms applied to the coils **206** by the circuit **310** so as to optimize rotation of the shaft.

Block **506** represents positioning the casing **208**, **218** so that the inner surface **304** faces the outer surface **222** of the shaft **204**, **216**. In one or more embodiments, the casing **208**, **218** is disposed concentrically about the shaft **204**, **216**.

Block **508** represents assembling the remainder of the gas turbine engine **200**, including positioning the nacelle **414**.

Block **510** represents connecting a circuit **310**, **404**. The electromagnets generate first magnetic fields **M1** when current is supplied to the electromagnets **302** from the circuit **310** (when the apparatus is operating as a motor **300**) or the circuit **404** receives current I induced in the coils **206** when the apparatus is operating as a generator **400**.

Block **512**, represents the end result, an apparatus comprising a motor **300** and/or generator/power generation device **400**.

The motor **300** comprises a gas turbine engine **200** including a rotor shaft **204** and a first casing **208** around the rotor shaft **204** ; a transmission **212** connecting the rotor shaft **204** to a gearbox **210**, the transmission **212** comprising a drive shaft **216** and a second casing **218** around the drive shaft **216**; one or more permanent magnets **202** attached to the rotor shaft **204** and/or the drive shaft **216**; one or more electromagnets **302** attached to the first casing **208** and/or the second casing **218**; and a power supply **310**a connected to the electromagnets **302**. The rotor shaft **204** turns

220 when the electromagnets **302** generate first magnetic fields M**1** in response to current I supplied from the power supply **310**a and the magnets **202** and electromagnets **302** are positioned such that the first magnetic fields M**1** interact with second magnetic fields M**2** generated by the permanent magnets **202**.

In one or more embodiments, the apparatus comprises a brushless DC motor **300** integrated with, or in situ on, the engine **200**, wherein the brushless DC motor **300** comprises the permanent magnets **202** and the electromagnets **302**.

In one embodiment, the rotating **306** comprises turning the shaft **204** by one or more partial turns (each partial turn less than one revolution) about axis AA'. In another embodiment, the rotating **220** comprises turning the shaft by more than one revolution about axis AA'.

The power generation device **400** includes a gas turbine engine **200** including a rotor shaft **204** and a first casing **208** around the rotor shaft **204**; a transmission **212** connecting the rotor shaft **204** to a gearbox **210**, the transmission **212** comprising a drive shaft **216** and a second casing **218** around the drive shaft **204**; one or more permanent magnets **202** attached to the rotor shaft **204** and/or the drive shaft **216**; and one or more coils **206** attached to the first casing **208** and/or the second casing **218**.

In one embodiment, an energy storage device **406** (e.g., a battery) is connected to the coils **206**. The energy storage device **406** stores electrical energy E generated by the coils **206** when the engine **200** is running so as to rotate **220** the permanent magnets **202** on the shaft **204**, **216** and magnetic fields M**2** generated by the permanent magnets **202** interact with the coils **206**.

In another embodiment, an aircraft electrical system **408** is connected to the coils **206**. The aircraft electrical system **408** receives electrical power P generated by the coils **206** when the engine **200** is running so as to rotate **220** the permanent magnets **202** on the shaft **204**, **216**, and the coils **206** and the permanent magnets **202** are positioned such that current I is generated in the coils **206** when the shaft **216**, **204** is rotating **220** and magnetic fields M**2** generated by the permanent magnets **202** interact with the coils **206**.

In one or more embodiments, the apparatus comprises a brushless DC generator **400** integrated with, or in situ on, the engine **200**, wherein the brushless DC generator **400** comprises the permanent magnets **202** and the coils **206**.

In one or more embodiments, the apparatus has dual use and the magnets **202**, the coils **206**, and the circuit **310**, **404** are configured so that the apparatus can be operated either as the generator **400** or the motor **300**. In one embodiment, a circuit is provided that includes circuits **310** and **404**, wherein the circuit comprise a switch switching between generator and motor operation.

Examples of the rotor shaft **204** include a low-pressure or a high-pressure shaft in a **2**-spool engine **200**, or a low-pressure or intermediate-pressure shaft in a **3** spool engine.

Block **514** represents connecting the generator or motor to an aircraft system.

In one embodiment, the generator **400** is connected to an electrical system **408** and/or energy storage device **406**, so that the current I generated by the generator charges the energy storage device **406** or provides current I to the electrical system **408**. The electrical power P is used to either power the airplane system **408** or an engine **200** system, e.g., to reduce transient and peak electrical power demands on the engine **200**. Typically, the engine is responsible for generating electrical power for its own engine systems using two different and conventional electrical generators on the engine. However, in one embodiment, the power generation device **400** could replace either of the conventional electrical generators on the engine **200**.

In another embodiment, the motor **300** is connected to a controller wherein the controller controls the rotation of the rotor **108** using the motor. The nacelle **414** comprises trapped air **116** creating a temperature gradient perpendicular to a longitudinal axis AA' of the rotor shaft **204**. Interaction of the first magnetic field M**1** and second magnetic field M**2** turns **306** the rotor shaft **204** so as to cool the rotor shaft **204** and/or reduce or prevent thermal bowing of the rotor shaft **204** in the temperature gradient T when the gas turbine engine **200** is cooling down after shutdown of the gas turbine engine **200**. In one example, the motor **300** is activated to rotate **306**, **220** the rotor shaft **204** prior to engine start (i.e., prior to motoring the engine **200**, and wherein motoring refers to rotating the shaft after engine start but prior to fuel on).

Processing Environment

FIG. **6** illustrates an exemplary system **600** that could be used to implement processing elements needed to control the integrated motor or generator **300**, **400** described herein. The computer system is typically located on the aircraft e.g., but not limited to, in a box mounted on the engine fan case or inside the aircraft.

The computer **602** comprises a processor **604** (general purpose processor **604**A and special purpose processor **604**B) and a memory, such as random access memory (RAM) **606**. Generally, the computer **602** operates under control of an operating system **608** stored in the memory **606**, and interfaces with the user/other computers to accept inputs and commands (e.g., analog or digital signals) and to present results through an input/output (I/O) module **610**. The computer program application **612** accesses and manipulates data stored in the memory **606** of the computer **602**. The operating system **608** and the computer program **612** are comprised of instructions which, when read and executed by the computer **602**, cause the computer **602** to perform the operations herein described. In one embodiment, instructions implementing the operating system **608** and the computer program **610** are tangibly embodied in the memory **606**, thereby making a computer program product or article of manufacture. As such, the terms "article of manufacture," "program storage device" and "computer program product" as used herein are intended to encompass a computer program accessible from any computer readable device or media.

In one embodiment, computer **602** comprises one or more field programmable gate arrays (FPGAs).

The computer system **600** is connected a circuit energizing the electromagnets or receiving current generated in the coils.

In one embodiment, an Electronic Engine Control (EEC) sending a digital request to the computer **602** through I/O **610** to reduce, increase, select timing of, and/or modify electrical current and/or voltages supplied to the integrated motor **300** in order to rotate the rotor **204**, thus controlling HP compressor **108** speeds.

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In another embodiment, the EEC unit sends a digital request to the controller **602** through I/O **610** to control current and/or voltage outputted from the integrated generator **400**, so as to control flow the current or application of the voltage to the electrical system **408** or energy storage device **406**. In yet another embodiment, the computer provides status to the EEC so that the controller and/or the EEC monitor system monitor performance and/or control the rotation of the rotor or supply of power to the electrical system.

In one embodiment, the computer **602** is connected to a flight management system via I/O **610**. The flight management system comprises a computer **418** controlling fuel consumption of the engine **200** during flight, in response to power P provided to the electrical system **408** or the engine **200** by the integrated generator **630**, **400**.

In one embodiment, the I/O **610** receives signal from an engine shut off switch after engine **200** shut down, thereby activating the integrated motor **300** so as to transfer energy/torque to the rotor shaft **204**. In one example, the integrated motor **300** rotates the rotor soon/immediately after engine shut down so as to minimize aircraft departure delays caused by mitigating rotor shaft bow. In another embodiment, the computer **602** activates the means transferring energy from the flywheel to the rotor, so as to rotate the rotor prior to engine start (i.e., prior to motoring the engine).

In another embodiment, the duration of rotation **306** is optimized by having the computer **602** estimate the amount of bow (based on time since last engine shutdown) and calculate the required rotation duration to be implemented. Various instrumentation to monitor the bowing can include accelerometers already used for vibration monitoring or microwave-based gap measuring sensors.

FIG. **6** further illustrates a power source **616** for providing power to the system **600**.

Those skilled in the art will recognize many modifications may be made to this configuration without departing from the scope of the present disclosure. For example, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used.

Conclusion

This concludes the description of the preferred embodiments of the present disclosure. The foregoing description of the preferred embodiment has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of rights be limited not by this detailed description, but rather by the claims appended hereto.

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EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A motor, comprising:

a gas turbine engine including a rotor shaft and a first casing around the rotor shaft;

a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft;

one or more permanent magnets, wherein:

the one or more permanent magnets are attached to the rotor shaft, or

the one or more permanent magnets are attached to the drive shaft, or

one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft;

one or more electromagnets, wherein:

the one or more electromagnets are attached to the first casing, or

the one or more electromagnets are attached to the second casing, or

one or more of the electromagnets are attached to the first casing and one or more of the electromagnets are attached to the second casing;

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a power supply connected to the electromagnets, wherein the rotor shaft turns when:

the electromagnets generate first magnetic fields in response to current supplied from the power supply, and

the first magnetic fields interact with second magnetic fields generated by the permanent magnets.

2. The motor of claim **1**, further comprising a nacelle housing the gas turbine engine, wherein:

the rotor shaft has a longitudinal axis (AA'),

the nacelle traps air, creating a temperature gradient perpendicular to the longitudinal axis (AA'); and

interaction of the first and second magnetic fields turns the rotor shaft so as to reduce or prevent thermal bowing of the rotor shaft in the temperature gradient when the gas turbine engine is cooling down after shutdown of the gas turbine engine.

3. The motor of claims **1** or **2**, wherein the permanent magnets are on the rotor shaft and the electromagnets are on the first casing.

4. The motor of any one of claims **1-3**, further comprising a direct current (DC) motor integrated with the gas turbine engine, wherein the DC motor comprises the permanent magnets and the electromagnets.

5. The motor of any one of claims **2**-**4**, wherein the permanent magnets are on the drive shaft and the electromagnets are on the second casing.

6. The motor of any one of claims **2**-**5**, wherein the gas turbine engine comprises a high pressure compressor including the rotor shaft.

7. The motor of any one of claims **1**-**6**, wherein the gearbox does not include an engine turning motor.

8. A power generation device, comprising:

a gas turbine engine including a rotor shaft and a first casing around the rotor shaft;

a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft;

one or more permanent magnets, wherein:

the one or more permanent magnets are attached to the rotor shaft, or
the one or more permanent magnets are attached to the drive shaft, or

one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft;

one or more coils, wherein:

the one or more coils are attached to the first casing, or

the one or more coils are attached to the second casing, or

one or more of the coils are attached to the first casing and one or more of the coils are attached to the second casing;

an energy storage device connected to the coils, wherein:

the energy storage device stores electrical energy generated by the coils when:

the engine is running so as to rotate the permanent magnets on the shaft, and

magnetic fields generated by the permanent magnets interact with the coils; and the electrical energy reduces transient and peak electrical power demands on the engine.

9. The power generation device of claim **8**, wherein the energy storage device comprises a battery.

10. The power generation device of claims **8** or **9**, wherein the permanent magnets are on the rotor shaft and the one or more coils are on the first casing.

11. The power generation device of any one of claims **8-10**, wherein the permanent magnets are on the drive shaft and the one or more coils are on the second casing.

12. The power generation device of any one of claims **8-11**, wherein the gas turbine engine comprises a high pressure compressor including the rotor shaft.

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13. A power generation device, comprising:

a gas turbine engine including a rotor shaft and a first casing around the rotor shaft;

a transmission connecting the rotor shaft to a gearbox, the transmission comprising a drive shaft and a second casing around the drive shaft;

one or more permanent magnets, wherein:

the one or more permanent magnets are attached to the rotor shaft, or

the one or more permanent magnets are attached to the drive shaft, or

one or more of the permanent magnets are attached to the rotor shaft and one or more of the permanent magnets are attached to the drive shaft;

one or more coils, wherein:

the one or more coils are attached to the first casing, or

the one or more coils are attached to the second casing, or

one or more of the coils are attached to the first casing and one or more of the coils are attached to the second casing;

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an aircraft electrical system connected to the coils, wherein:

the aircraft electrical system receives electrical power generated by the coils when:

the engine is running so as to rotate the permanent magnets on the shaft, and

magnetic fields generated by the permanent magnets interact with the coils.

14. The power generation device of claim **13**, wherein the electrical power is used to either power an airplane system or an engine system.

15. The power generation device of claims **13** or **14**, wherein the gearbox does not include an engine turning motor.

16. The power generation device of any one of claims **13**-**15**, wherein the permanent magnets are on the rotor shaft and the one or more coils are on the first casing.

17. The power generation device of any one of claims **13**-**16**, wherein the permanent magnets are on the drive shaft and the one or more coils are on the second casing.

18. An aircraft comprising the apparatus of any one of claims **13**-**17**, further comprising a computer connected to the engine, wherein:

the current powers the electrical system during times of peak electrical loading of the electrical system, and the computer reduces fuel consumption in the gas turbine engine as compared to when the gas turbine engine is used to power the electrical system during the times of peak electrical loading without the current from the coils.

19. The power generation device of any one of claims **13-18**, further comprising a brushless DC generator integrated with the engine, wherein the brushless DC generator comprises the permanent magnets and the coils.

20. The power generation device of any one of claims **13-19**, wherein the gas turbine engine comprises a high pressure compressor including the rotor shaft.

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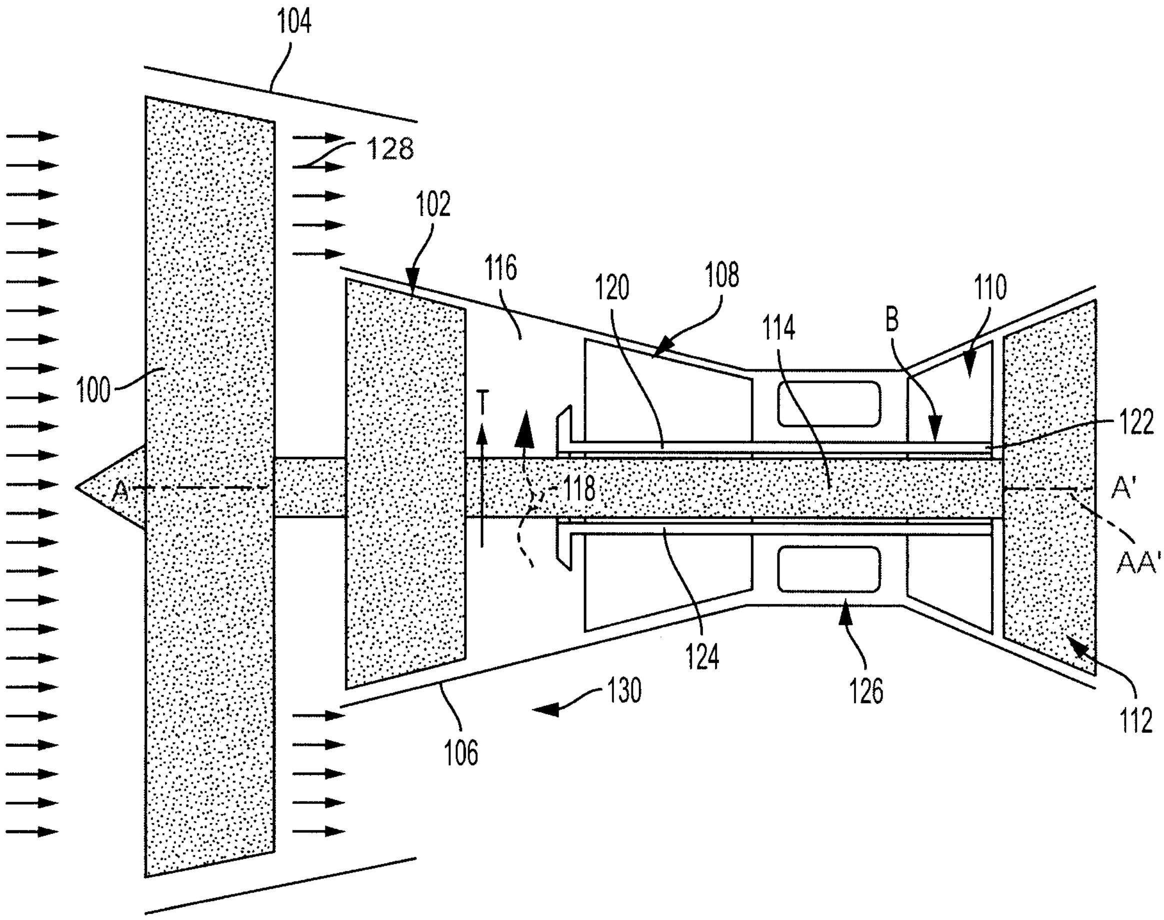

104
128
102
116
120
108
114
B
110
100
T
122
A
118
A'
AA'
124
126
130
112
106

FIG. 1

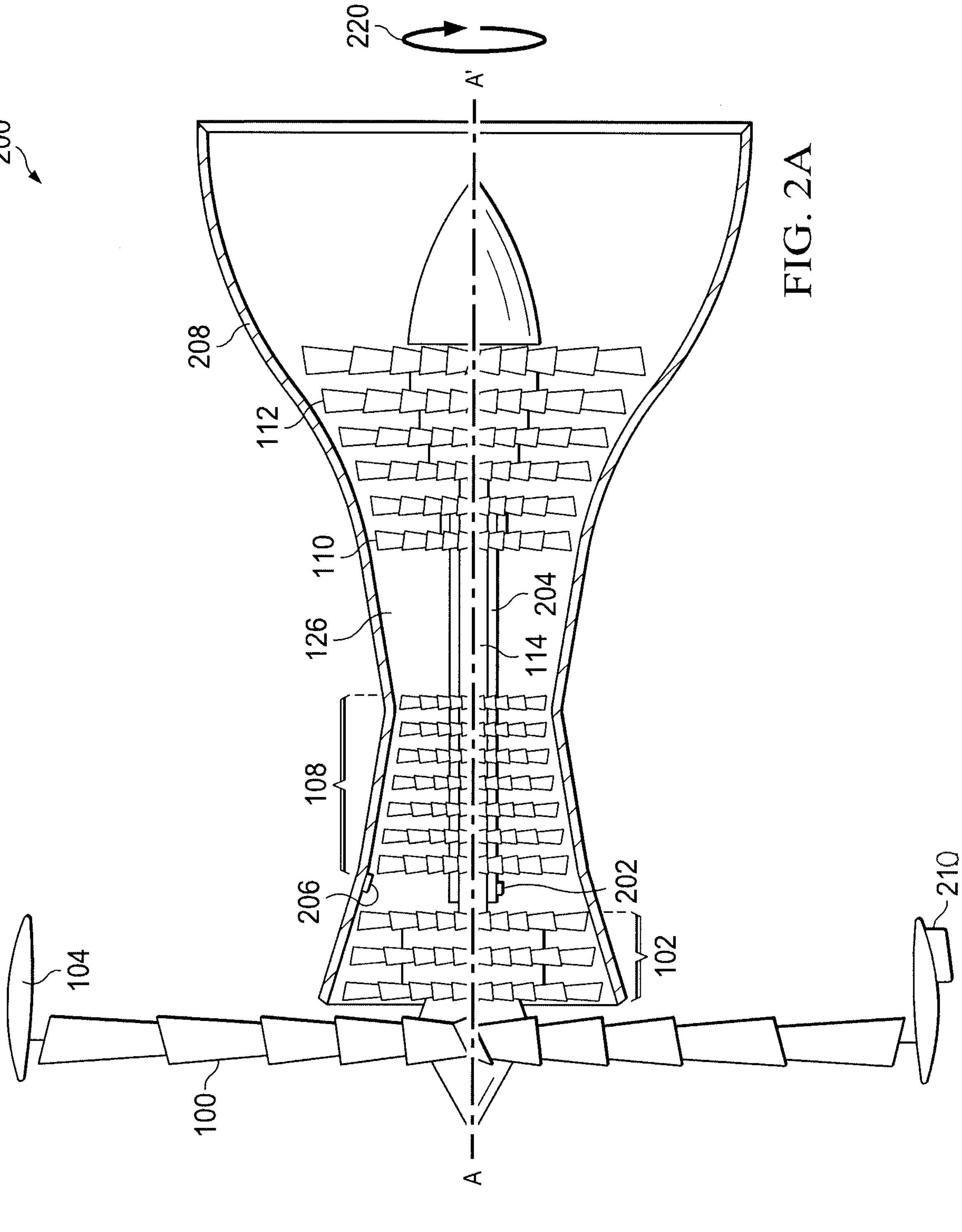


FIG. 2A

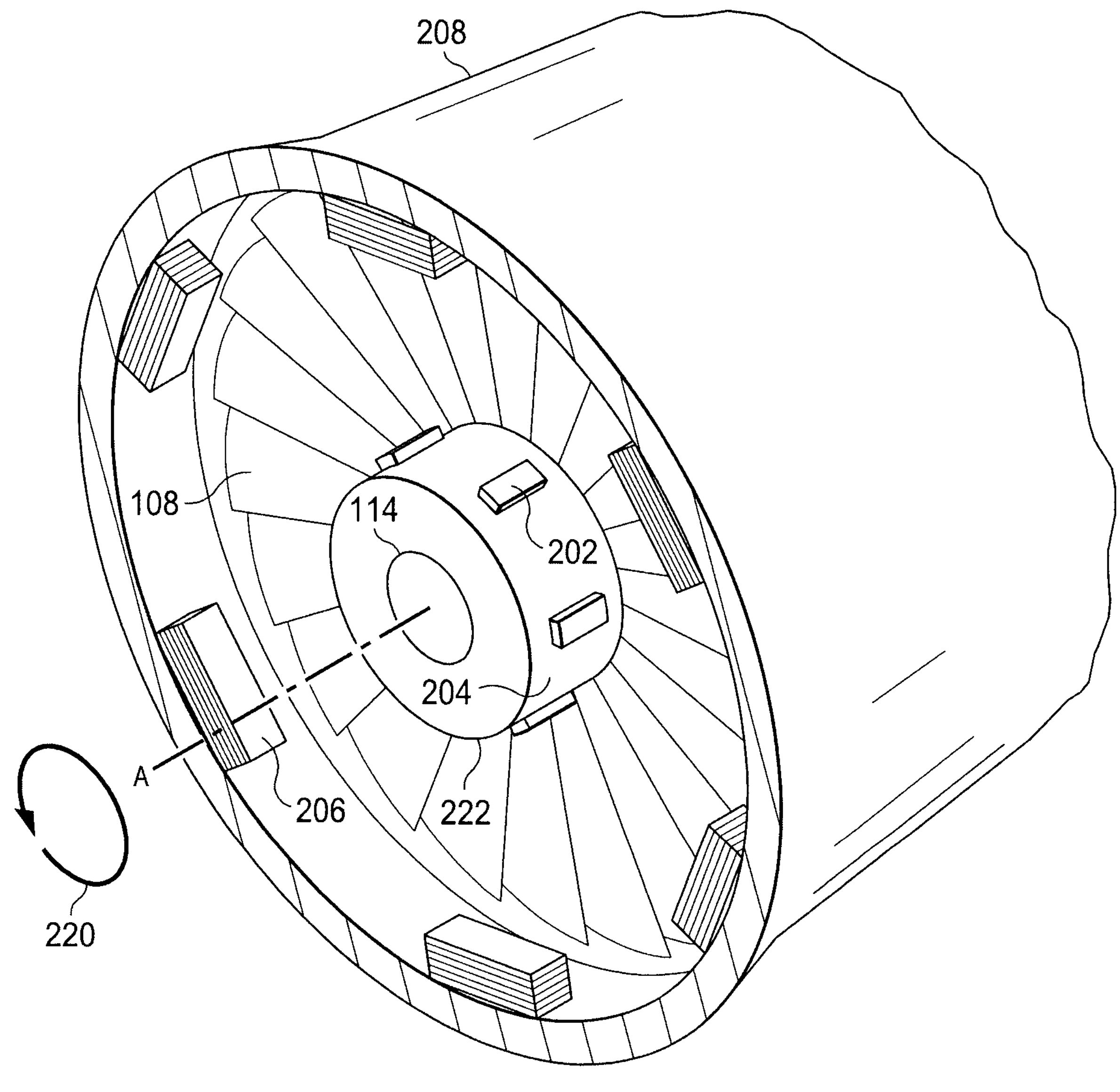


FIG. 2B

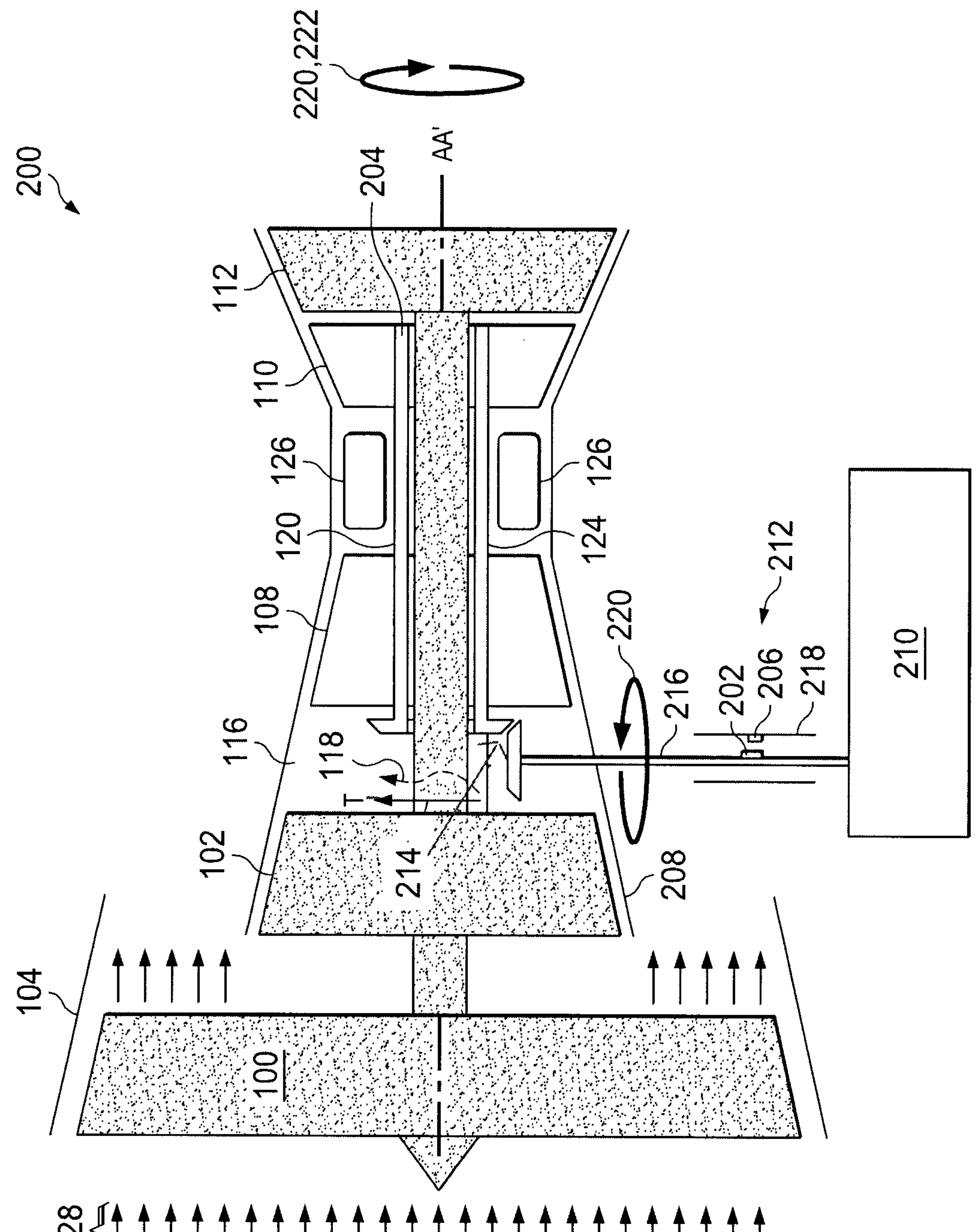

200
220,222
AA'
204
112
110
126
126
120
124
108
212
220
216
202
206
218
210
116
118
T
102
214
208
104
100
128

FIG. 2C

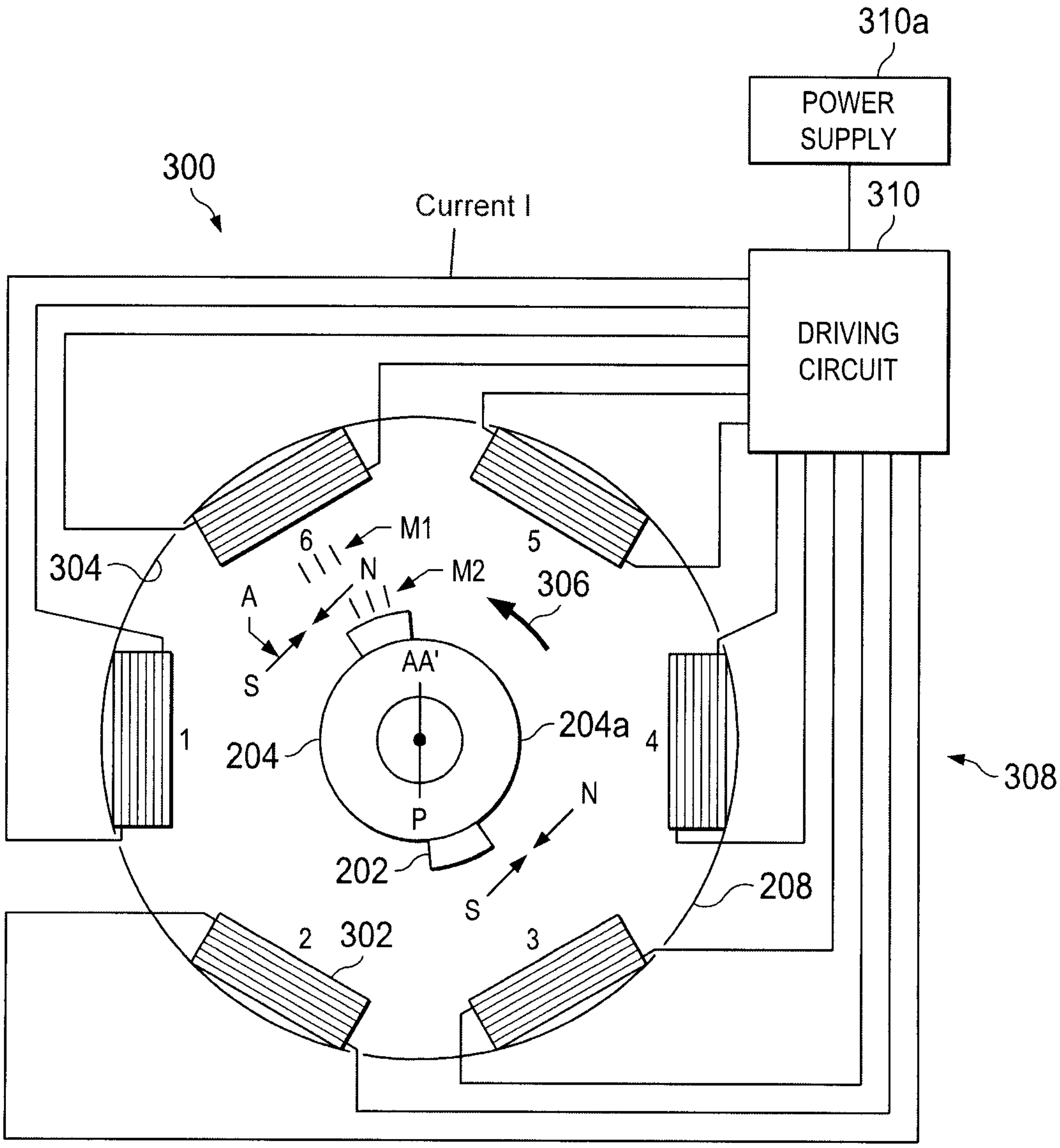
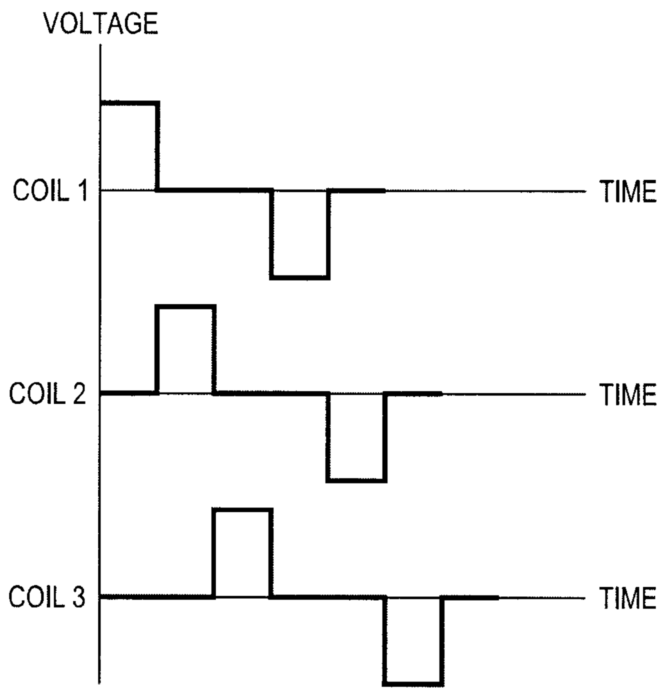

310a
POWER SUPPLY
300
Current I
310
DRIVING CIRCUIT
M1
6
5
304
N
M2
306
A
S
AA'
1
204
204a
4
308
N
P
202
208
S
2
302
3

FIG. 3A


VOLTAGE
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TIME
COIL 2
TIME
COIL 3
TIME

FIG. 3B

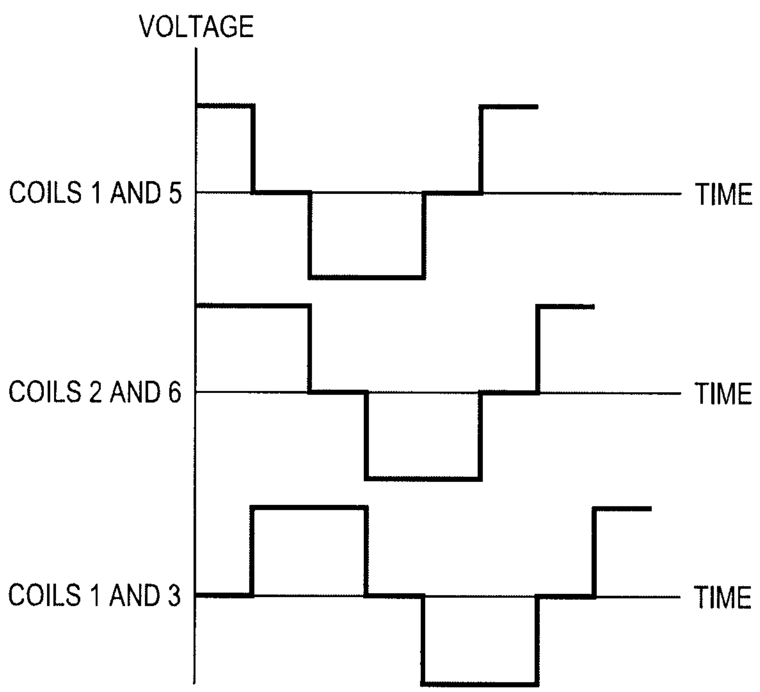

VOLTAGE
COILS 1 AND 5
TIME
COILS 2 AND 6
TIME
COILS 1 AND 3
TIME

FIG. 3C

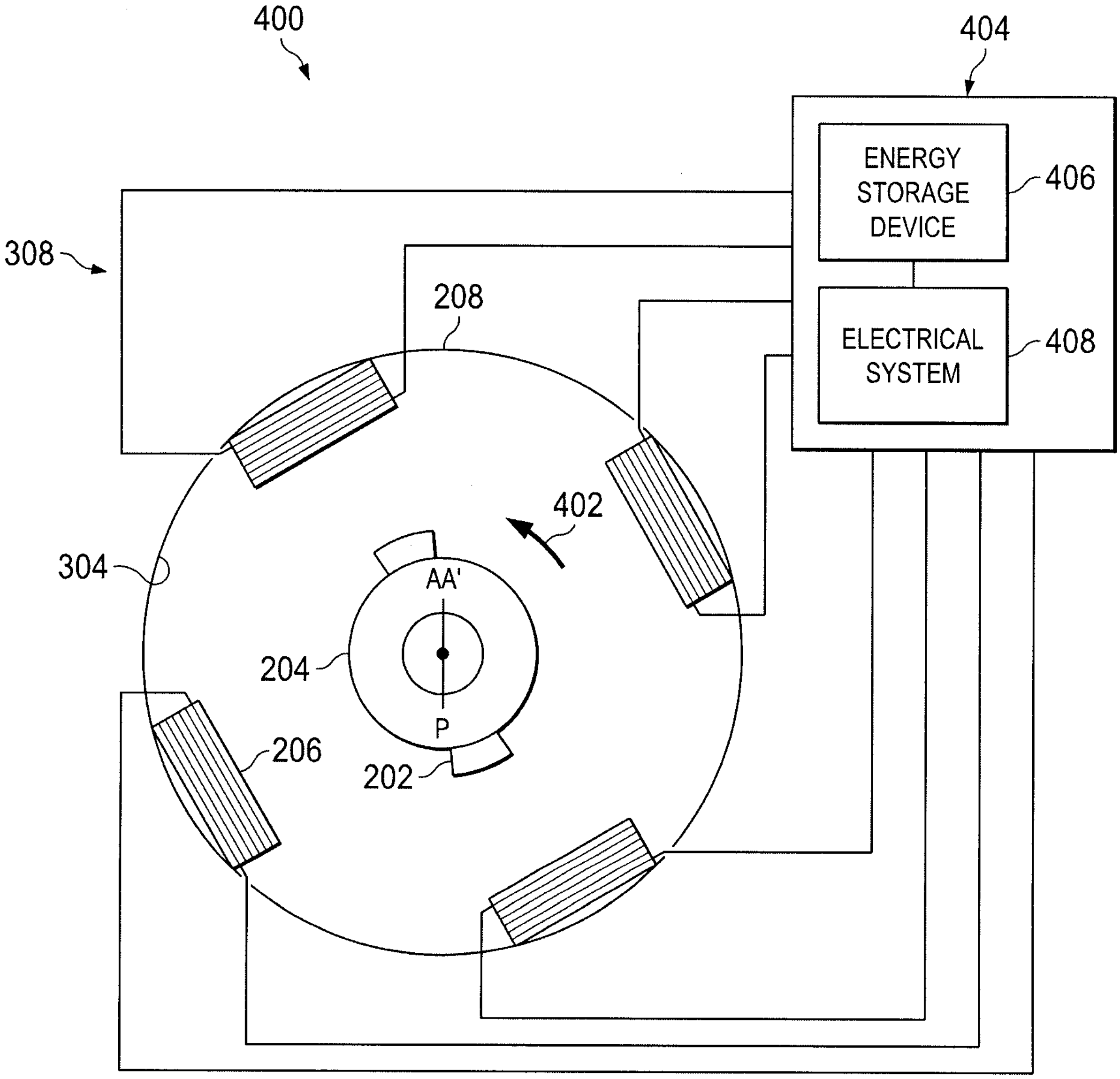

400
404
ENERGY
STORAGE
DEVICE
406
ELECTRICAL
SYSTEM
408
308
208
402
304
AA'
204
P
206
202

FIG. 4A

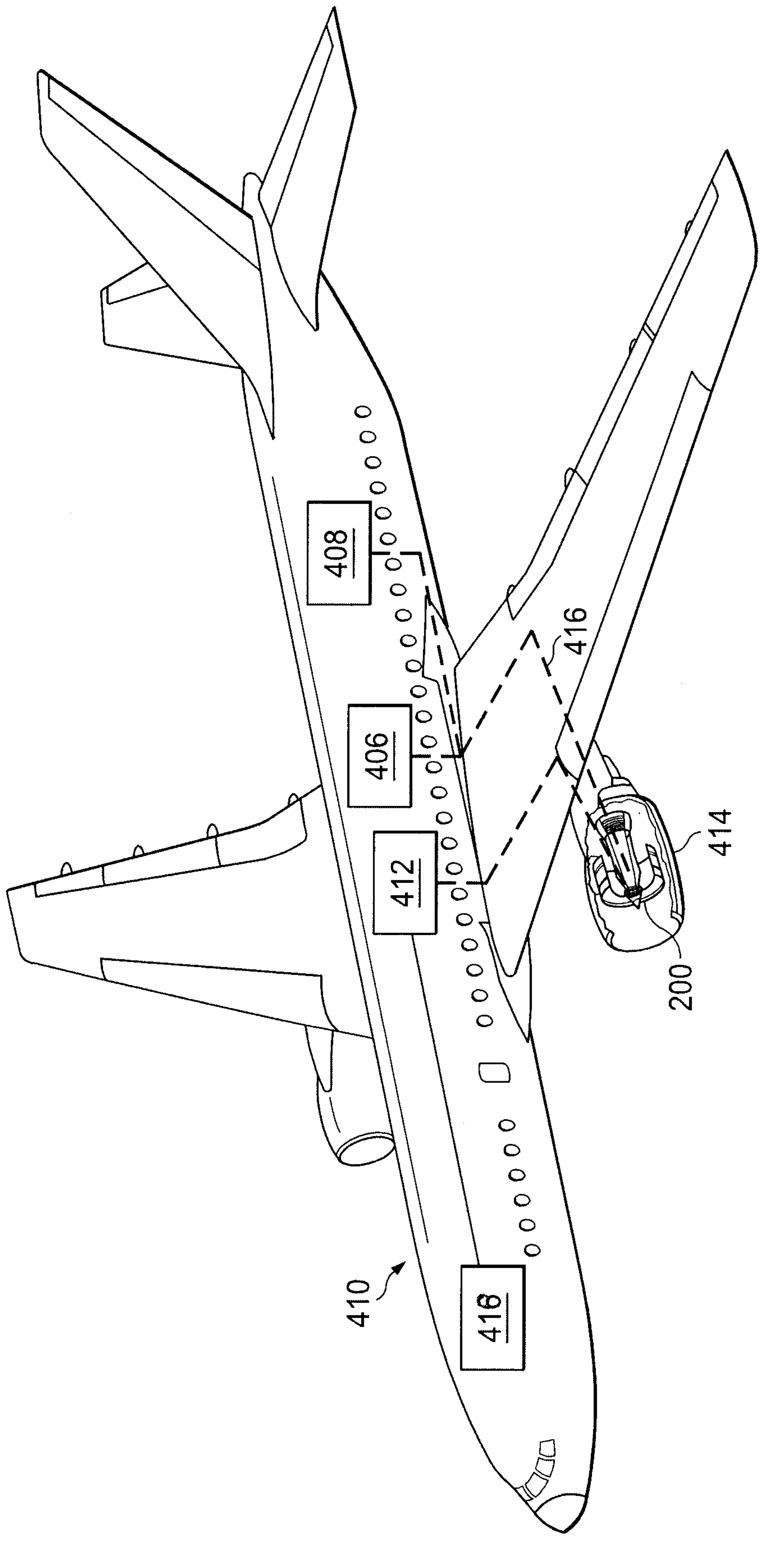
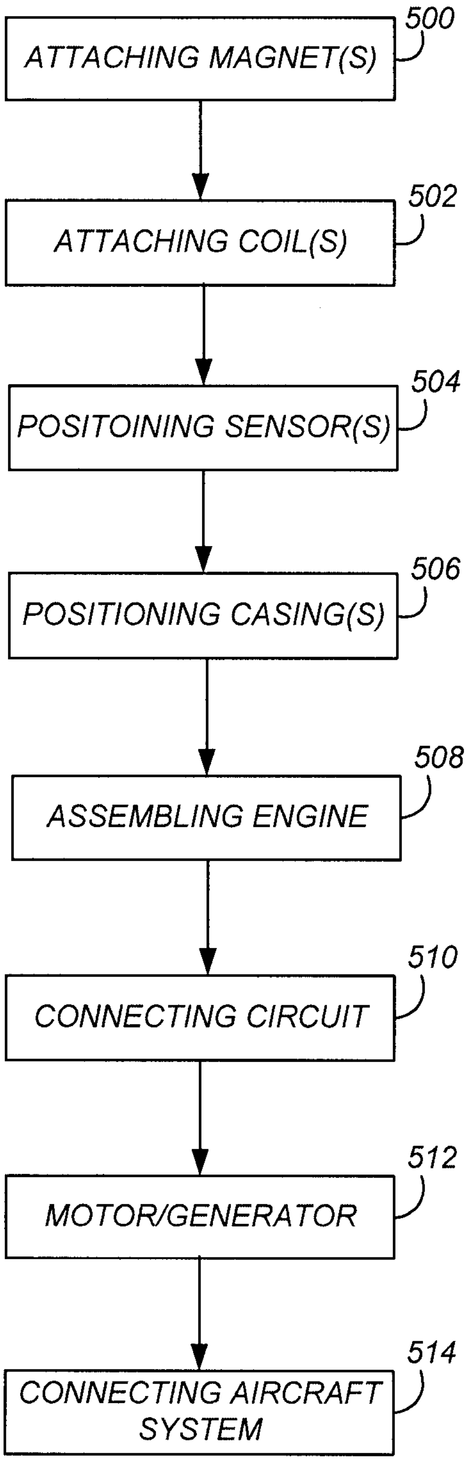


FIG. 4B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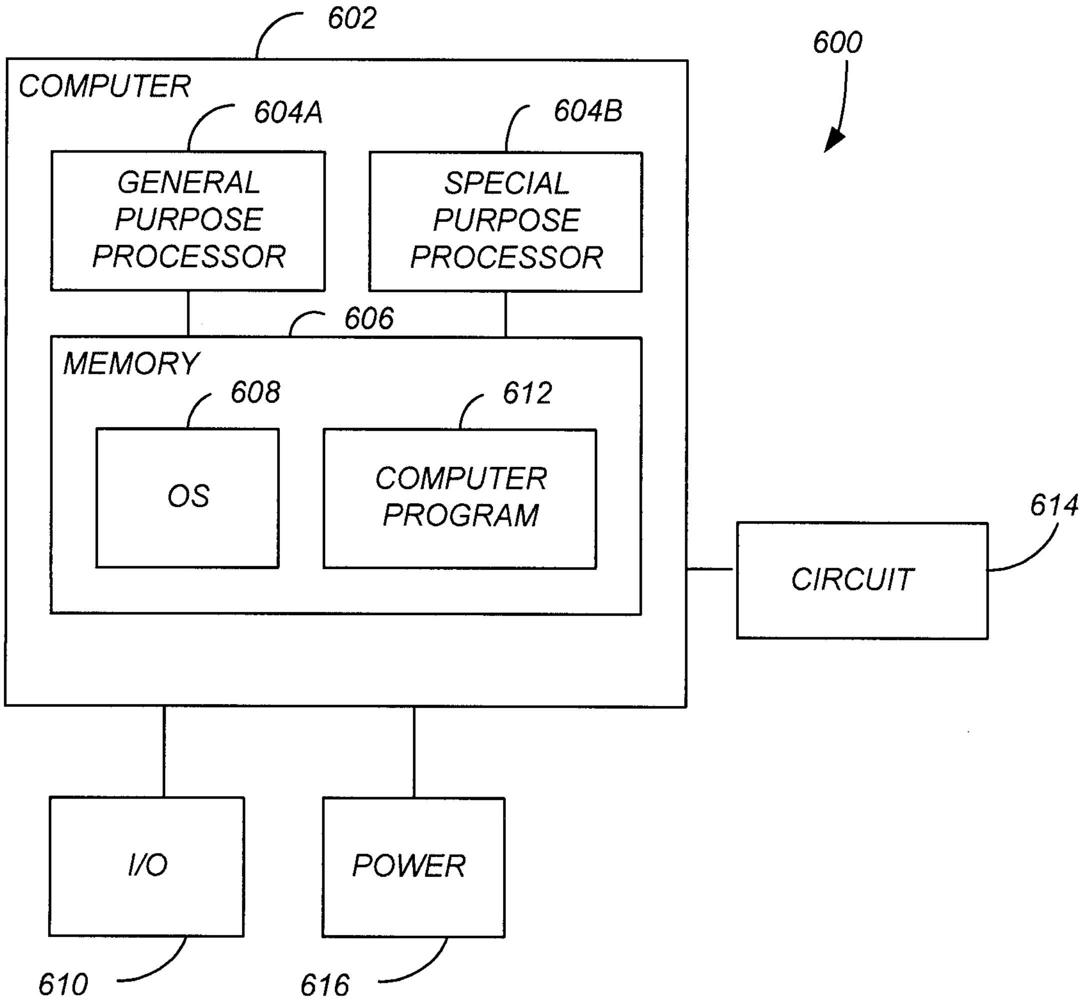
ATTACHING COIL(S)
502
POSITOINING SENSOR(S)
504
POSITIONING CASING(S)
506
ASSEMBLING ENGINE
508
CONNECTING CIRCUIT
510
MOTOR/GENERATOR
512
CONNECTING AIRCRAFT SYSTEM
514

FIG. 5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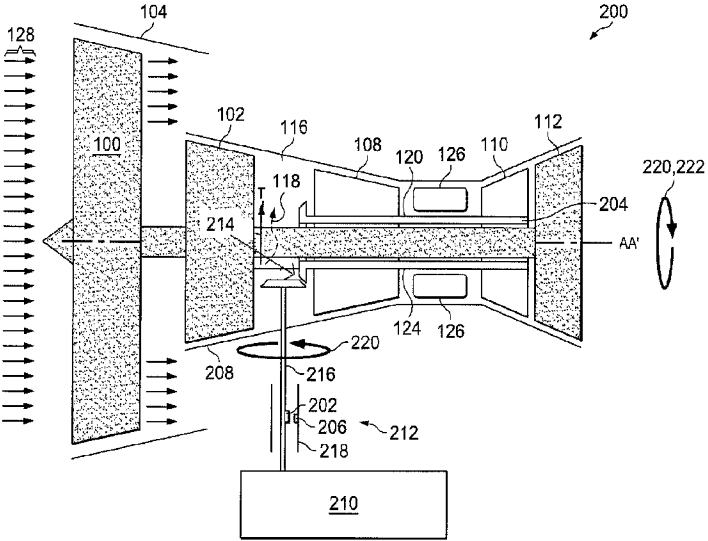
600
COMPUTER
604A
604B
GENERAL PURPOSE PROCESSOR
SPECIAL PURPOSE PROCESSOR
606
MEMORY
608
612
OS
COMPUTER PROGRAM
614
CIRCUIT
I/O
POWER
610
616

FIG. 6


104
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128
100
102
116
108
120
126
110
112
118
T
204
220,222
214
AA'
124
126
220
208
216
202
206
212
218
210

C